Annals of Clinical and Analytical Medicine
Original Research

Should we rely on electrolyte values measured by venous blood gas analysis in children with critical illness?

Electrolyte values measured by venous blood gas analysis in children

Sefika Bardak[1], Emel Berksoy[1], Gülşah Demir[1], Alper Çiçek[1], Şule Demir[2], Elif Yiğit[3], Pelin Elibol[4], Tuğçe Nalbant[5], Gamze Gökalp[5]
[1] Department of Pediatric Emergency, University of Health Sciences, Tepecik Research and Training Hospital, Izmir
[2] Department of Pediatric Emergency, Maternity and Children's Diseases Hospital, Aydin
[3] Department of Pediatrics, University of Health Sciences, Tepecik Research and Training Hospital, Izmir
[4] Department of Pediatric Emergency, Faculty of Medicine, University of Ege, Izmir
[5] Department of Pediatric Emergency, University of Katip Çelebi, Tepecik Research and Training Hospital, Izmir, Turkey

Abstract
Aim: In this study, we aimed to compare venous blood gas analysis and auto-analyzers for obtaining levels for sodium, potassium, and glucose in critically ill patients and to investigate the correlation between results.
Material and Methods: Sodium, potassium, and glucose values obtained by two methods simultaneously were evaluated separately for three groups' pH status: acidosis, normal pH, and alkalosis.
Results: A total of 198 paired measurements were recruited. A statistically significant difference was found between blood gas analyzer and auto-analyzer methods in terms of sodium (136.78 ± 10.553 mmol/l; 136.78 ± 6.686 mmol/l), potassium (4.307 ± 0.881 mmol/l; 4.529 ± 0.902 mmol/l), and glucose (182.89 ± 83.39 mg/dl; 163.44 ± 99.108 mg/dl) ($p < 0.05$). A Bland-Altman plot of difference suggested that all agreements between venous blood gas analysis and auto-analyzer were good (the latter measure was considered the standard).
Discussion: Differences between electrolytes and glucose values obtained with both techniques vary according to the pH state.

Keywords
Biochemistry, Blood Gas Analysis, Critical Care, Electrolyte, Glucose

DOI: 10.4328/ACAM.21515 Received: 2022-11-28 Accepted: 2022-12-31 Published Online: 2023-01-05 Printed: 2023-04-01 Ann Clin Anal Med 2023;14(4):345-349
Corresponding Author: Emel Berksoy, Department of Pediatric Emergency, University of Health Sciences, Tepecik Research and Training Hospital, Izmir, Turkey.
E-mail: emelberksoy@hotmail.com P: +90 505 252 06 55
Corresponding Author ORCID ID: https://orcid.org/0000-0002-6831-1353
This study was approved by the Clinical Research Ethics Committee of University of Health Sciences, Tepecik Training and Research Hospital (Date: 2020-09-14, No: 2020/11-43)

Introduction

Among the routine laboratory measurements in pediatric emergency departments, glucose, sodium, and potassium are the primary and necessary parameters in the management of critical patients requiring rapid intervention [1-3]. Although laboratory assessments (auto-analyzer method) are conventional and reliable, waiting for results in life-threatening situations such as shock can worsen the outcome [4]. In such cases, blood gas analysis (BGA) is an alternative method used to obtain test results in a few minutes. Utilization of direct ion-selective electrode technology with BGA offers important advantages such as evaluating acid-base status with a small blood sample, as well as providing electrolyte levels [5, 6]. Despite all these advantages, the majority of clinicians do not rely on electrolyte values determined by BGA in patient management [7, 8].

There are studies in the literature, which are mostly conducted on adult patients that evaluate the reliability of BGA in terms of sodium, potassium, and glucose measurement, but the results are inconsistent [5, 9-14]. Critical patient distinction was not made in most studies evaluating the reliability of electrolyte and glucose values obtained with BGA [8, 9, 11, 15]. Studies conducted on critically ill patients are insufficient [5,16]. For this reason, it has become necessary to compare electrolyte measurements obtained with BGA with those obtained with the auto-analyzer (AA) and to show consistency between them in critical child patient management.

Critical illness and/or critical injury are defined as diseases and/or injuries that reduce or potentially reduce oxygen delivery to the tissues [17]. Blood gas analysis is one of the first-step laboratory assessments in critically ill patients because it enables the evaluation of acid-base balance, oxygenation, and ventilation.

In this study, we aimed to compare sodium, potassium, and glucose levels obtained by venous BGA and AA in critically ill patients and to investigate the correlation between results. We also wanted to find out whether changes in acid-base balance cause any difference between the results obtained with these two techniques.

Material and Methods

A retrospective, observational, and cross-sectional study was conducted in the pediatric emergency clinic of a tertiary care hospital with 170,000 average annual admissions. Patients (0–18 years of age) with critical illness and unstable vital signs in the pediatric emergency room between January 2016 and December 2019 were included. Measurements using BGA and AA were studied with blood samples taken simultaneously from the peripheral venous route, and the results were obtained from patient files and hospital information system records. Patients with respiratory, circulatory, and/or neurological disorders and abnormal vital signs were included in the study.

Patient age, gender, admission diagnosis, venous blood gas parameters (pH, sodium, potassium, and glucose), AA measurements (sodium, potassium, and glucose), and disposition data (intensive-care-hospital inward admission, exitus, emergency observation) were recorded. Patients with incomplete data, or who had received intravenous fluid or any treatment before blood was drawn, or whose blood samples were not taken simultaneously, or whose vital signs were stable were excluded from the study.

Venous blood gas samples were taken into a heparinized injector (dry, containing 72 IU / 2 ml Lithium heparin) and studied within 2 minutes with a daily calibrated device (ABL800 FLEX; Radiometer Medical ApS, Copenhagen, Denmark) in a pediatric emergency room. All blood samples taken from critically ill patients were delivered to the pediatric emergency department laboratory within 5 minutes by the service personnel. Venous blood samples were taken into a serum separator tube and electrolyte results were obtained within 60–90 minutes via the AA (AU680; Beckman Coulter, Indianapolis, Indiana).

Simultaneous BGA and AA measurement values were evaluated separately for three groups as acidosis (pH < 7.35), normal pH (pH = 7.35–7.45), and alkalosis (pH > 7.45).

Statistical Analysis

Descriptive statistics for variables were specified as mean, standard deviation, median, minimum value, maximum value, and percentage. Homogeneity of variances, which is one of the prerequisites of parametric tests, was checked with Levene's test, and normality assumption was evaluated with the Shapiro-Wilk test. Differences between three and more groups were compared with one-way analysis of variance and Tukey HSD [honestly significant difference] test when parametric test prerequisites were met, and the Kruskal-Wallis analysis and Bonferroni-Dunn test when not provided. The Pearson correlation coefficient was calculated for each parameter: between 0.30 and 0.70 was considered a moderate correlation, and between 0.71 and 0.99 a strong correlation. In comparison, laboratory measurement results were determined as the gold standard. The consistency between measurement techniques was evaluated with the Bland-Altman chart (mean and 95% Limits of Agreement = LoA). Data were evaluated via SPPS 20 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and $p < 0.05$ was considered significant.

Ethical Approval

Ethics Committee approval for the study was obtained. Since our study was conducted retrospectively, informed consent was not obtained from the patients.

Results

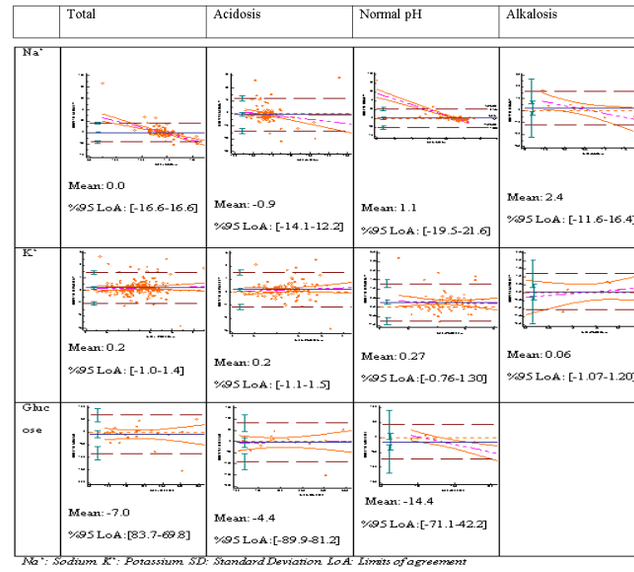
In total, 198 children (125 males, 73 females) with a mean age of 41.06 ± 57.67 months (range: 0.2 –218.9) were recruited. Electrolyte measurement values were recorded in all patients with BGA and AA. While glucose measurements were available in all patients with an AA, measurements could only be obtained in 27 (13.6%) patients via BGA. Demographic data and clinical characteristics of the patients are shown in Table 1.

When classifying the study group according to acid-base balance, it was found that 110 (55.6%) patients were in the normal pH group, 80 (40.4%) patients were in the acidosis group, and 8 (4%) patients were in the alkalosis group.

There was a moderate correlation in terms of sodium ($r = 0,59$; $p = 0.001$) and a strong correlation in terms of potassium ($r = 0.76$; $p = 0.001$) and glucose ($r = 0.88$; $p = 0.001$) between the two measurement techniques (Tables 2, 3).

Table 1. Demographic and clinical data of patients.

Demographic and clinical data		
Gender (n/%)	Male	125 (63.1)
	Female	73 (36.9)
Age (months) (mean ± SD) (minimum-maximum)		41.06 ± 57.67
		0.2-218.9
Admission diagnosis (n/%)	Respiratory problems	129 (65.2)
	Trauma	33 (16.7)
	Shock	17 (8.6)
	Status epilepticus	7 (3.5)
	Poisoning	4 (2)
	Heart failure	2 (1)
	Congenital metabolic disorders	4 (2)
	Electrical injury	1 (0.5)
	Elevated intracranial pressure	1 (0.5)
Disposition (n/%)	Ward	89 (44.9)
	ICU	100 (50.5)
	Exitus	9 (4.5)
	Total	198 (100)



Na+: Sodium K+: Potassium SD: Standard Deviation LoA: Limits of agreement

Figure 1. Bland-Altman plots for sodium, potassium and glucose levels (means and LoAs) in venous blood gas analysis and auto-analyzer for each pH status.

Table 2. Statistical analysis results for Sodium (Na+) and (K+) levels.

Na^+ (mmol/l)	Total n=198	Normal pH n=80	Acidosis n=110	Alkalosis n=8	Test Statistics	p
BGA (n=198)						
mean+SD	136.78±10.553	134.61±11.642	138.73±9.294	131.63±10.756	7.639	0.022* ψ
[median]IQR	[137.00]6	[136.50]5‡	[138.00]5†	[130.50]16‡		
AA (n=198)						
mean+SD	136.78±6.686	135.66±3.987	137.79±8.037	134.00±5.806	5.175	0.075ψ
[median]IQR	[136.00]4	[136.00]4	[137.00]4	[133.50]8		
p	0.001*	0.001*	0.001*	0.020*		
r	0.598	0.453	0.710	0.789		
BGA (n=198)						
mean+SD	4.307±0.881	4.189±0.775	4.381±0.954	4.463±0.789	1.679	0.432ψ
[median]IQR	[4.200]1.0	[4.200]0.8	[4.200]1.1	[4.450]1.3		
AA (n=198)						
mean+SD	4.529±0.902	4.459±0.744	4.580±1.001	4.525±0.979	0.539	0.764ψ
[median]IQR	[4.550]1.1	[4.500]1.0	[4.550]1.2	[5.100]1.8		
p	0.001*	0.001*	0.001*	0.015*		
r	0.765	0.762	0.765	0.807		

*p<0.05; IQR: Inter-Quartile-Range; ψ Kruskal Wallis Test; SD: Standard Deviation, BGA: Blood Gas Analysis, AA: Auto-analyzer; †,‡ Sodium levels are statistically significantly higher in acidosis group in BGA

Table 3. Statistical analysis results for Glucose levels.

Glucose (mg/dl)	Total n=198	Normal pH n=80	Acidosis n=110	Alkalosis n=8	Test Statistics	p
BGA (n=27)						
mean+SD	182.89±83.39	139.86±64.904	201.74±85.82	126.0±	5.339	0.069ψ
[median]IQR	[163.0]124	[107.0]87	[167.0]135	[126.0]		
AA (n=198)						
mean+SD	163.44±99.108	140.46±77.377	183.79±111.28	113.38±24.657	5.755	0.004*Δ
[median]IQR	[134.0]108	[119.50]72†	[158.0]105‡	[103.50]48§		
p	0.001*	0.001*	0.001*	0.329		
r	0.889	0.967	0.874	0.399		

Δ Analysis of Variance (ANOVA); *p<0.05; IQR: Inter-Quartile-Range; ψ Kruskal-Wallis Test; SD: Standard Deviation, BGA: Blood Gas Analysis, AA: Auto-analyzer, †,‡,§ Glucose levels differ statistically significantly between pH groups (p<0.05). This is due to acidosis and normal pH groups. Only 1 subject could be gathered for alkalosis group in BGA. Thus, SD and IQR could not be calculated.

When the differences were evaluated according to pH groups, linear positive correlation was found with r values of 0.45 for sodium, 0.76 for potassium, 0.88 for glucose in the normal pH group between the two measurement techniques ($p < 0.05$). Linear positive correlation was found in the acidosis and alkalosis groups for both sodium and potassium ($p < 0.05$) (Tables 2, 3).

Tables 2, 3 also compare the mean values of all measurements by BGA and AA of all three pH groups. Sodium values determined by BGA in the acidosis group were statistically more significant other pH levels ($p < 0.05$). This statistical difference was not detected in the measurements examined by AA (Table 2). It was determined that the potassium measurement was not affected by different pH conditions in both measurement techniques (Table 2). While glucose levels obtained via BGA were not affected by pH levels, a statistical difference was found between all three pH groups for AA measurements ($p < 0.05$) (Table 3).

When evaluating the agreement between the two methods with Bland-Altman, 95% LoA was -16.6–16.6 (mean 0.0) for sodium, -1.0–1.4 (mean 0.2) for potassium and -83.7–69.8 (mean -7.0) for glucose (Figure 1).

Discussion

Rapid evaluation of electrolytes is very important in making decisions quickly, regulating fluid and medical treatments in management of critically ill children, and is often lifesaving. Blood gas analysis is one of the indispensable examinations in pediatric emergency services in management of critically ill children, especially in infants, due to its important advantages, such as working with minimal blood samples, giving fast results in electrolyte values, and not being affected by serum proteins [18, 19]. As shown in many studies, it is understood that the differences between the electrolyte values obtained from BGA and AA are due to the chemical reaction differences between these two techniques and BGA working with whole blood and AA with serum.

In the United States Clinical Laboratory Improvement Amendment (US CLIA), differences of ± 0.5 mmol/L in potassium levels, ± 4 mmol/L in sodium levels, and ± 6 mg/dL in glucose levels can be accepted with standard calibration [5, 20].

This study shows that there is a significant difference between sodium, potassium, and glucose measurements obtained with BGA and AA, including all pH groups. It is remarkable that sodium levels were found to be significantly higher with BGA than AA measurements, especially in the acidosis group. However, there are studies in the literature showing that the electrolyte levels obtained with BGA were found to be lower compared to AA [6, 16]. It is thought that this difference may be due to the dilution of additional heparin or due to heparin binding to electrolytes [5, 6]. On the other hand, we think that using a dry heparin injector causes sodium levels to be higher in BGA compared to AA. In addition, higher potassium levels in AA measurements may be due to the centrifugation of blood samples or delayed analysis.

There are studies in the literature evaluating the reliability of electrolyte and glucose levels obtained with BGA [5, 8, 9, 11, 13-15, 21-24]. However, the results of these studies vary. In the study conducted by Altunok et al. [11] in adult patients a strong correlation between sodium and potassium and a moderate correlation between glucose levels were found between these analysis methods. However, it was reported that the difference was not acceptable limits for any parameter. Similar to our study, patients were compared according to their pH status, but unlike our results, it was concluded that the measurements did not differ according to their pH status [11].

With the Bland-Altman plot, we observed a good agreement between the two measurement techniques in terms of sodium and potassium levels, since the mean difference is at acceptable levels and the scatter plots are in the agreement range.

When the agreement was evaluated according to pH groups, it was found that sodium values were better in the acidosis group and the potassium values in the alkalosis group. In terms of glucose values, it was determined that there was an agreement in the acidosis group compared to the normal pH group, with findings suggesting that the total group was not consistent. Since glucose levels can be measured in only one patient and other parameters in eight patients in the alkalosis group, we think that a clear interpretation cannot be made about compliance and reliability. While glucose level could be measured in 198 patients with laboratory measurement, glucose level could be measured in only 27 patients in BGA. Therefore, it would not be appropriate to comment on glucose levels in general and especially in the alkalosis group.

Laboratory tests are evaluated after clinical evaluation and necessary vital interventions in pediatric emergency departments. First interventions should be decided according to the clinical findings of the patient. We think it would be appropriate that verification of abnormal values in BGA with an AA confirmation should not be required if the BGA results correlate with clinical findings.

Limitations

The most important limitation of our study is that it was conducted in a single center and is retrospective. An insufficient number of patients in the alkalosis group to evaluate patients according to their pH status, as well as the low number of glucose results obtained by BGA, constitute limitations in terms of interpretation. Nevertheless, the strength of this study is that this is the first study to compare electrolytes measurements between venous BGA and AA for different pH status in a population of critically ill children. Larger population and multicenter studies investigating the reliability of measurements with BGA in the management of critically ill children are needed.

Conclusion

Our results confirm that sodium levels measured via venous BGA were statistically significantly higher in patients with acidosis, whereas potassium levels do not differ according to pH conditions in both methods. While potassium levels measured via venous BGA can be trusted, care should be exercised in critically ill patients, as sodium values may differ by pH conditions. Eventually electrolyte values should be confirmed with laboratory analysis, if possible, when sodium levels are not compatible with clinical findings.

Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

Funding: *None*

Conflict of interest
None of the authors received any type of financial support that could be considered potential conflict of interest regarding the manuscript or its submission.

References
1. Batra P, Dwivedi AK, Thakur N. Bedside ABG, electrolytes, lactate and procalcitonin in emergency pediatrics. Int J Crit Illn Inj Sci. 2014;4(3): 247-52.
2. Weiss SL, Peters MJ, Alhazzani W, Agus MSD, Flori HR, Inwald DP, et al. Surviving sepsis campaign international guidelines for the management of septic shock and sepsis-associated organ dysfunction in children. Intensive Care Med. 2020; 46(Suppl. 1):10-67.
3. Lee JW. Fluid and electrolyte disturbances in critically ill patients. Electrolyte Blood Press. 2010; 8(2):72-1.
4. Blick KE. Providing critical laboratory results on time, every time to help reduce emergency department length of stay: How our laboratory achieved a six sigma level of performance. Am J Clin Pathol. 2013;140(2):193–2.
5. Jain A, Subhan I, Joshi M. Comparison of the point-of-care blood gas analyzer versus the laboratory auto-analyzer for the measurement of electrolytes. Int J Emerg Med. 2009;2(2):117–20.
6. Yip PM, Chan MK, Zielinski N, Adeli K. Heparin interference in whole blood sodium measurements in a pediatric setting. Clin Biochem. 2006;39(4):391–95.
7. Gray TA, Freedman DB, Burnett D, Szczepura A, Price CP. Evidence based practice: Clinicians' use and attitudes to near patient testing in hospitals. J Clin Pathol. 1996;49(11):903–8.
8. Zhang JB, Lin J, Zhao XD. Analysis of bias in measurements of potassium, sodium and hemoglobin by an emergency department-Based blood gas analyzer relative to hospital laboratory autoanalyzer results. PLoS One. 2015;10(4): e0122383.
9. Uysal E, Acar YA, Kutur A, Cevik E, Salman N, Tezel O. How reliable are electrolyte and metabolite results measured by a blood gas analyzer in the ED? Am J Emerg Med. 2016;34(3):419–4.
10. Uyanik M, Sertoglu E, Kayadibi H, Tapan S, Serdar MA, Bilgi C, et al. Comparison of blood gas, electrolyte and metabolite results measured with two different blood gas analyzers and a core laboratory analyzer. Scand J Clin Lab Invest. 2015;75(2): 97-5.
11. Altunok İ, Aksel G, Eroğlu SE. Correlation between sodium, potassium, hemoglobin, hematocrit, and glucose values as measured by a laboratory autoanalyzer and a blood gas analyzer. Am J Emerg Med. 2019;37(6):1048–53.
12. Elahian F, Sepehrizadeh Z, Moghimi B, Mirzaei SA. Human cytochrome b5 reductase: Structure, function, and potential applications. Crit Rev Biotechnol. 2014;34(2):134-3.
13. Chacko B, Peter JV, Patole S, Fleming JJ, Selvakumar R. Electrolytes assessed by point-of-care testing - Are the values comparable with results obtained from the central laboratory? Indian J Crit Care Med. 2011;15(1):24–9.
14. Morimatsu H, Rocktäschel J, Bellomo R, Uchino S, Goldsmith D, Gutteridge G. Comparison of point-of-care versus central laboratory measurement of electrolyte concentrations on calculations of the anion gap and the strong ion difference. Anesthesiology. 2003;98(5):1077–84.
15. Budak YU, Huysal K, Polat M. Use of a blood gas analyzer and a laboratory autoanalyzer in routine practice to measure electrolytes in intensive care unit patients. BMC Anesthesiol. 2012;12:17.
16. Chhapola V, Kanwal SK, Sharma R, Kumar V. A comparative study on reliability of point of care sodium and potassium estimation in a pediatric intensive care unit. Indian J Pediatr. 2013;80(9):731–5.
17. Shaw KN, Bachur RG, editors. Fleisher & Ludwig's Textbook of Pediatric Emergency Medicine. 8th ed. Philadelphia, PA: Wolters Kluwer; 2021. p. 26–2.
18. King RI, Mackay RJ, Florkowski CM, Lynn AM. Electrolytes in sick neonates - Which sodium is the right answer? Arch Dis Child Fetal Neonatal Ed. 2013;98(1):F74-6.
19. Arthurs O, Pattnayak S, Bewley B, Kelsall W. Clinical impact of point-of-care testing using the OMNI-S blood gas analyzer in a neonatal intensive care setting. Point Care. 2010;9(1): 21–4.
20. Ehrmeyer SS, Laessig RH. Has compliance with CLIA requirements really improved quality in US clinical laboratories? Clin Chim Acta. 2004;346(1):37-3.
21. Xie H, Lv S, Chen S, Pang Z, Ye D, Guo J, et al. Agreement of Potassium, Sodium, Glucose, and Hemoglobin Measured by Blood Gas Analyzer With Dry Chemistry Analyzer and Complete Blood Count Analyzer: A Two-Center Retrospective Analysis. Front Med (Lausanne). 2022;9:799642.
22. Ahmet K, Ebru C. Can the clinician trust blood gas for serum electrolyte levels? J Clin Anal Med. 2019; 10(2): 151-5.
23. Kaya O, Yucel K. Comparison of the sodium, potassium, chloride and glucose levels measured by a blood gas analyzer and an autoanalyzer. Annals of Medical Research. 2021; 27(10): 2639–44.
24. Katherine E T, Bradley A W, Richard N, Dana A H, Liesel E H, Samantha T, et al. Can the blood gas analyser results be believed? A prospective multicentre study comparing haemoglobin, sodium and potassium measurements by blood gas analysers and laboratory auto-analysers. Anaesth Intensive Care. 2019; 47(2):120–7.

How to cite this article:
Sefika Bardak, Emel Berksoy, Gülşah Demir, Alper Çiçek, Şule Demir, Elif Yiğit, Pelin Elibol, Tuğçe Nalbant, Gamze Gökalp*. Should we rely on electrolyte values measured by venous blood gas analysis in children with critical illness? Ann Clin Anal Med 2023;14(4):345-349*

This study was approved by the Clinical Research Ethics Committee of University of Health Sciences, Tepecik Training and Research Hospital (Date: 2020-09-14, No: 2020/11-43)